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Analyzing Evacuation Behavior of Able-Bodied Individuals in the Presence of Disabled Persons in Underground Metro Stations

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ABSTRACT

This study explores how able-bodied individuals behave during evacuation in underground metro station in the presence of disabled person. Metro station plays a crucial role in urban transportation but also had significant challenges due to improper layout, high crowd density and including vulnerable populations such as the elderly and disabled. To found evacuation pattern, many advanced technologies are used in this research such as Agent based modeling in Unity 3D for behavioral simulation and for design of 3D model of metro station, SketchUp Pro is used. A 2^3 full factorial experimental design was adopted and it include three main factors (number of evacuees, number of disabled people, presence of liftman) resulting in eight different evacuation scenarios. It was found that, the simulation revealed that evacuation time increased by as much as 35.5% with higher crowd density, higher number of people and disabled individuals. The presence of liftman reduced delays by 17.7%. A systematically survey data collected from 100 participants, analyzed by using, ANOVA, Tukey's HSD and regression analysis (adjusted $R^2 = 0.82$) And PCA. The finding showed that crowd congestion, signage etc. affect evacuation behavior. The study is done with the help of BIM and VR, which gives helpful ideas for making more safer metro station for everyone during emergencies.

Keywords: Emergency evacuation, underground metro stations, disabled individuals

1. BACKGROUND

Underground metro stations, which provides a large capacity along with effective and sustainable transit, are an essential part of urban transportation [1]. These technologies are essential for improving public transportation, minimizing environmental pollution, and easing traffic congestion. Metro systems are vital for urban planning as cities grow, offering a sustainable alternative to private cars and helping reduce reliance on fossil fuel, thereby decreasing greenhouse gas emission [2]. Over the last ten years, the number of riders on metro systems has increased significantly, underscoring their importance in contemporary transportation network. Metro systems are regarded as cost effective, efficient, and reliable, and they serve millions of computers every day. In urban areas, they reduce travel time for increasing economic productivity and improving connectivity [3]. They improve social inclusion by providing accessible transportation options for a variety of groups which makes it easier for people from a wide range of socioeconomic background to travel [4].

Underground metro systems need fast and effective evacuation plans for emergencies. A key challenge to evacuating metro infrastructure is the lack of efficient passenger guidance and clear emergency signage [1]. These signs are often poorly positioned or designed, reducing their visibility during high-pressure situations and causing confusing for commuters unfamiliar with the station's layout [2]. Due to hesitation, anxiety, and poor decisions about evacuation routes, people get confused and this causes more traffic jams [1]. In metro system, evacuating process is very hard because passengers include all ages people like children, adults, senior citizens who don't know the area and language and those with mental and physical difficulties [3]. Some people who have physical difficulties, faces many problems during emergencies because they can't move properly and fast [1]. Traditional metro station doesn't have elements like ramps for disabled people, easy to use emergency exits, or lifts for use in emergency situations [4,5]. People with physical

disabilities or other issues are at high risk during emergency situation in congested place like underground metro station because they can't move or walk properly [3].

It is challenging to understand how able people behave when evacuating with disabled people during an emergency situation, due to this reason, it is very difficult to create safe and better evacuation plans [6,4]. Most of the simulation models assumes every people act same in during evacuation, but in real world, this is not true, people behaves differently especially when able bodied people are evacuating with disabled bodied people or person with disabilities. Able bodied change their behaviour according to emergency situation and it is based on who they are with. [7,3]. In emergency situation, some people act differently, one of them able bodied help those people who have physical disabilities, some stop to help disabled people [8]. These differences can lead to delays and cause crowding [9]. Emotional and social factors like fear, stress and the feeling of responsibility also affect how people behave [11,12]. Most of the current evacuation models use very simple methods, they don't fully capture how people actually behave in emergencies [6]. They often use simple methods that ignore important factors like group behaviour, kindness and social influence. By including these real life behaviours, we can make more accurate simulations and improve emergency planning [9,10]. New technologies like Building Information Modelling, Virtual Reality and Agent Based Modelling helps to create detailed, smart and realistic models and simulation of buildings that show how different people interact with buildings. These tools helps to fix design problems [13,14]. VR technology creates realistic environments to see how people act or behave in different emergencies situations. Agent Based Modelling simulates how individuals make choices. Building Information Modelling helps to design and map out detailed metro station with accurate details. Together, these technologies helps to improve how spaces are used [14]. By using real world data, how people act in virtual reality during real emergencies, helps researchers can make more reliable and more accurate simulations [4,1]. This evidence based approach helps researchers understand how people behave differently with disabled people [10,16]. The main goal is to create safe and fair evacuation plans for underground transportation system, so that all people including disabled people, can evacuate safely [3,2]. This research focuses on how able-bodied people behave during emergencies situation in underground metro station, especially when disabled bodied are also present there. It studies how decisions are made, how people move, and what delays might happen. By using simulation tools like virtual reality, the goal is to create better, more inclusive evacuation plans [16]. The results will help to improve the safer design of metro station and more accessible for all passengers.

2. Research Methodology

2.1 Integrated Simulation-Based Research Design This study focuses on using simulation to analyze how people evacuate in underground metro station during an emergency situation. This simulation allows, researchers can recreate an emergency situations safely, to analyze evacuation behavior without ethical or logistical issues of involving real people, which can be challenging and ethically problematic [17]. Simulation plays an important role in evacuation study, it is used to study how able bodied and disabled bodied evacuate [18]. This research uses Agent Based Modeling, which can simulate individuals with different abilities, decision making styles and helping to understand how each person behave or respond in a group of number of people during an evacuation [20,6]. In emergency evacuation modeling, agent-based modeling (ABM) is used to simulate behaviors like panic, crowd bottlenecks, and reducing congestion during evacuation. [21,13]. In this study each person behaves differently, such as how fast they move, how quickly they react, how aware they are, showing the diversity of real world evacuees, including both able bodied and disabled bodied evacuees [18,8]. The detailed simulation shows both large crowd patterns, like crowd movement and individuals action such as asking for help or delays in exiting [4]. When simulating metro stations, it is important to consider how space, accessibility for disabled individuals affect movement, and design elements like elevators and escalators that affect how people move [22,1]. The model uses probability based functions to simulate decision making in stressful situations like respond to fire alarm and traffic jams [8]. Unity 3D is selected for its ability to manage collisions smoothly and it is also provide accurate movement [23,11]. SketchUp Pro was used to design the metro station layout and ensure it match with DMRC and NFPA 130 standards for space and accuracy [17,7]. A 2^3 full-factorial experimental design is used to create different evacuation scenarios by changing three factors: the total number of evacuees, the presence of individuals with disabilities, and the availability of support staff, such as lift operators. This approach helps analyze how these factors influence evacuation time, safety, and efficiency [3,24].

2.2 3D Spatial Modeling and Simulation Setup

An important part of this research is to creating a realistic 3D simulation of a metro station. For creating this, SketchUp Pro software is used, in which a detailed architectural 3D model of an underground metro station is made. This architectural 3D model include key elements like elevators, staircase, platform, ticket counters, signs, emergency exists and open waiting areas. [15].For more accurate design, official guidelines under DMRC and NFPA 130 should be followed for designing and planning. For exported 3D metro station model in Unity 3D, file format should be using like OBJ and FBX, because they keep model's data accurate [24]. In Unity, MavMesh tool is used to help agents can walk. It help people walk smoothly around realistically crowd and avoiding obstacles [7,26]. In this 3D model, to create an emergency situation like fire and power failures, C+ scripts are used. By using C+ scripts, it helps to make the simulation process more reliable.

Figure 1 3D View of Underground Metro Station in SketchUp

Figure 2 SketchUp 3D View of Metro Station During Evacuation

Figure 3 Cross-Sectional View of Underground Metro Station in SketchUp 3D

This interaction allows agents to modify their behavior in response to environmental cues and simulates actual evacuation situations [12,5]. Agent behavior scripts incorporate critical behavioral logics such as rerouting owing to congestion, delay in route switching under stress, and the potential for one agent to assist another—a feature that is particularly crucial in inclusive evacuation modeling [18,6]. As evidenced by actual evacuation studies, crippled agents, for instance, may prompt adjacent able-bodied agents to seek assistance, simulating social solidarity [24,27]. Advanced characteristics like the visibility of guide signage and how it affects decision-making are also analyzed because, particularly in complicated locations, signage is essential for cutting down on evacuation time [11,4]. To make evacuation experience more realistic, in simulation sound signals, flashing lights, alarms are added [28]. By combining this 3D detailed metro station model and realistic human behavior and advance tools like MavMesh and C + script, the study creates a strong and inclusive system for finding the realistic human behavior during emergency situation in underground metro station.

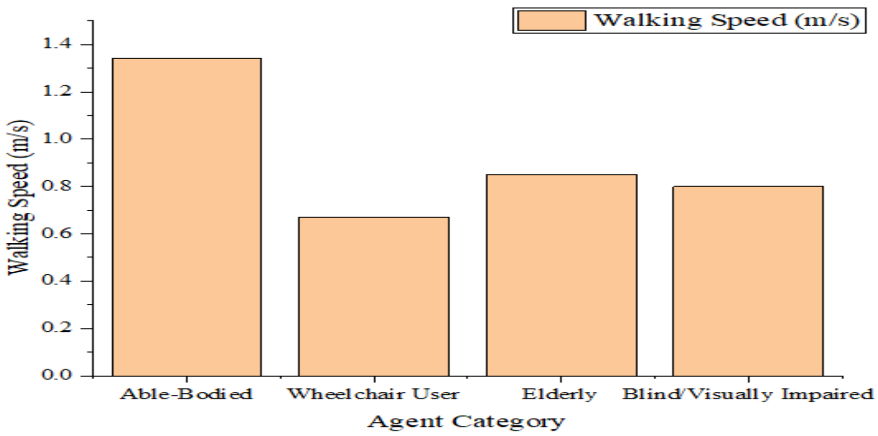

Figure 4 Average Walking Speeds of Different Agent Categories

This graphically representation shows how fast different type of groups of people move during the evacuation simulation. Able bodied move faster as compared to wheel chair users. Elderly people move slowly than able bodied but they move faster than wheelchair users and blind/visually impaired. These speed differences are more important to include to make realistic evacuation [18,19]. Table 1 shows that how many software's are used to create a realistic evacuation. Like Sketchup Pro is used to create a 3D model, Unity 3D helps to agent movement, MavMesh helps to allowing people in the simulation to walk, C+ programming is used to study the agent decision like how they react during evacuation. To simulate a real danger like fire, fire dynamics simulators (FDS) are used to create smoke. While unity scripting is used for dynamic events during simulation [7,14].

Table 1 Key Components in Simulation Setup

Component	Function	Software/Standard
3D Model	Structural representation of metro station	SketchUp Pro
Simulation Engine	Agent movement, crowd interaction	Unity 3D
Navigation System	Pathfinding logic for agents	NavMesh (Unity)
Behavior Scripts	Defines individual agent decisions	C+ Programming
Fire Emergency Events	Smoke spread, alarm, hazard zones	FDS Standards
Evacuation Routes	Predefined exit paths and obstacles	Based on DMRC/NFPA 130
Environmental Triggers	Dynamic events during simulation	Unity scripting

3. Emergency Scenario Design and Factorial Framework

This study uses a 2^3 full factorial design to find how different factors affect the people behavior during evacuate in emergency in underground metro station [6]. This include three factors: how many disabled bodied are present (1 or 2), how much total number of people are evacuating (6 or 12) and other factor is whether there is lift man present or not. These factors help to study, how each agent affect evacuation time and how they interact each other. The study focuses on these three factors because these factors affect the movement of agents and what kind of need they are required during an evacuation [18]. By changing these factors in different simulation, the study creates eight scenarios (S1-S8). This scenarios helps to analyze how each scenario affect crowd density, evacuation time and how people behave, what path they are choosing [4]. Agent based modeling is used in this study, which means it simulate each person in the evacuation, which include how people move, how they behave or respond, and may or may one help other evacuees, especially in case of wheel chair people or disabled bodied [17]. By using factorial design, it makes easier to analyze what factors affecting evacuation process [21]. This design allow researchers to compare different evacuation situation in a clear way, it follows earlier studies that suggested to improve how public transport systems are prepared for emergencies [20,21]. It helps to make the result more useful and create better emergency plans for metro station [29,30].

3.1 Conceptual Framework for Respondent Demographics in Evacuation Dynamics

For this study, we include 100 people to represent a mix of typical metro users. It includes both men (52) and women(48) because both gender can behave differently in emergencies [23]. We include 20 disabled bodied with 80 able bodied to understanding how people with different evacuate together [6]. Because disabilities can lead to slower movement and reacts , the study also find how able bodied respond, whether they stop for help or not [8].

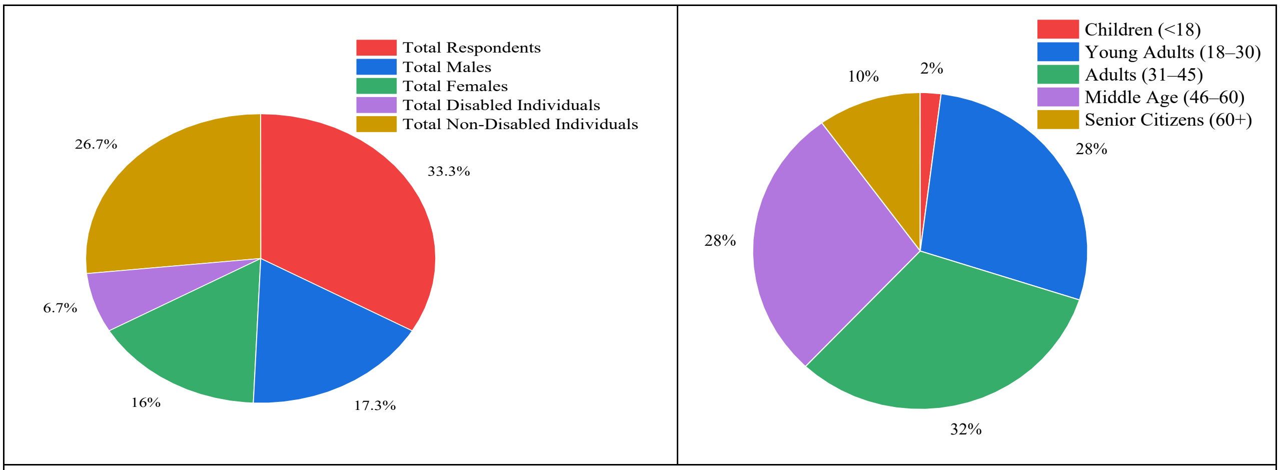

Figure 5 & 6 Distribution of Respondent Demographics by Age, Gender and Disability.

This study includes wide range from various age groups for showing different physical and cognitive abilities [4].The ages range from under 18, there are two participants. Under 18-30 include 28 participants, between 31-45, also contain 28 participants and 10 participants comes over 60 age [9]. The younger people come under age (18-30) are very faster than as compared to people who comes over 60, they are tend to move slower because of physical challenges. This age range helps to researchers to analyze how different age people affecting evacuation during emergency [19]. This study also uses these age-based insights in a simulation model that test three factors, in eight different scenarios in Table 2.

Table 2 2^3 Full Factorial Scenario Matrix

Scenario ID	Number of Evacuees	Disabled Individuals	Liftman Availability
S1	Low (6)	1	No
S2	Low (6)	1	Yes
S3	Low (6)	2	No
S4	Low (6)	2	Yes
S5	High (12)	1	No
S6	High (12)	1	Yes
S7	High (12)	2	No
S8	High (12)	2	Yes

The average evacuation time for each of the eight scenarios (Table 2) compared by the bar chart in Figure 7. In this chart, it shows that which setups are faster or slower. For example, scenario with more disabled people or no without liftmen, take longer to evacuate because of mobility issues. Figure 7 provides a visual representation of how the characteristics of each scenario affect the overall evacuation time.

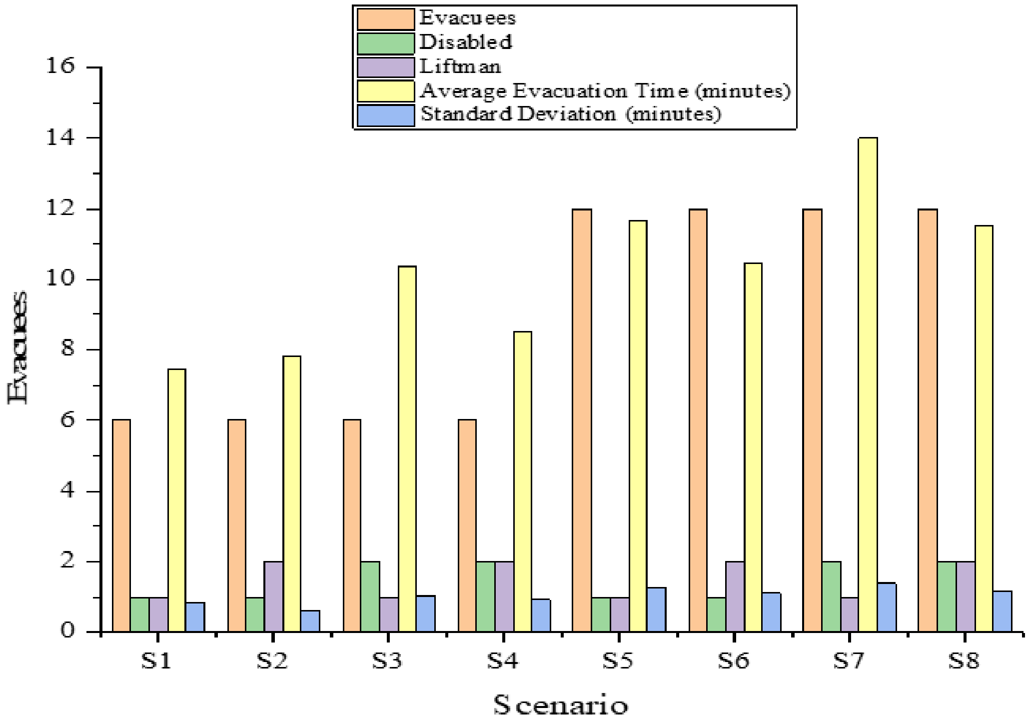

Figure 7 Scenario-wise Average Evacuation Time

4. Simulation Execution and Data Collection

The evacuation process was tested across the eight scenarios using 3D model of a metro station built in Unity. Each scenario was created to mimic real fire emergencies, it includes factors like elevator failures, smoke spreading and changes number of people to simulate a fire emergency. The agents and virtual people in the simulation moved to their own using shortest path, could change path if needed and interact with the station. Each agent has their own unique characteristics such as speed, visibility and behavior, how they follow crowd. Data was collected for both the overall system and for each individual people to study how crowd respond during emergency situation. This study measured various factors to understand the evacuation process at the both system and individual levels. At the system level, they looked at the thing like the overall exit speed, which routes are used most, where the crowd became most congested and how long the evacuation takes. For each individual agent, how long it takes each person to evacuate, how long they waited at crowded spots, and whether able-bodied agents help others. All of this data was automatically collected by Unity's analytics system. After the simulation process, to understand how people felt about the evacuation scenarios, a systematic survey was collected to feedback from people who participate in evacuation process. Total 100 participants took part, they watched the simulation videos on a screen or experienced them through virtual reality and they shared their thoughts on things, how easy the evacuation was to follow, how stressed they felt, how clearly the signs were and what improvement could be made to the station. The survey tool was tested and it showed strong reliability with a Cronbach's alpha of 0.83, it means that all questionaries were consistent and trustworthy [10].

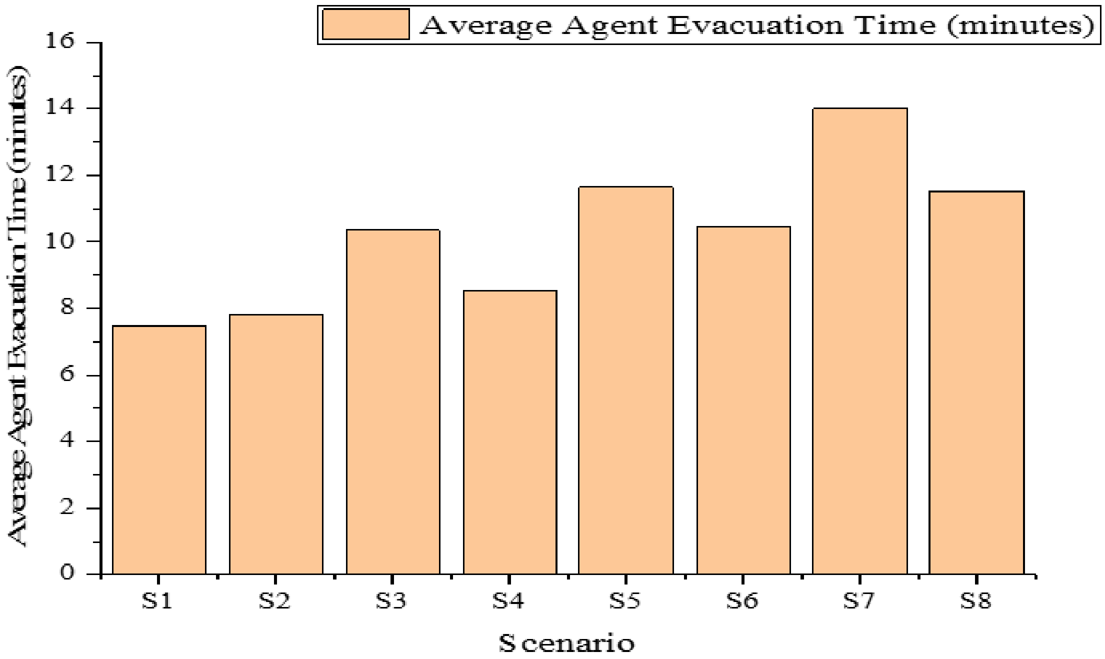

Figure 8 Average Agent Evacuation Time Across Scenarios

The chart showing average agent evacuation time across scenarios that helps sharpen the analysis by clearly focused how different factor like crowd size, disabled individuals, availability of liftman. It highlights the need for importance of planning for every one's safety by including vulnerable groups (Figure 8).

5. RESULTS AND DISCUSSIONS

5.1 Evacuation Time Analysis

In emergency situations, evacuation time is a critical performance metric, particularly in underground metro environments with vertical circulation restrictions and spatial bottlenecks. The combined impact of three main variables—the total number of evacuees (low = 6; high = 12), the number of disabled people (1 or 2), and the presence or absence of liftman support—was assessed using data collected from eight simulation scenarios (S1 to S8) using Unity-based 3D evacuation models. Evacuation time was found to gradually increase as occupant load and the number of disabled people increased, especially in situations where liftmen were not present. An example of this is Scenario S3, which had an average evacuation duration of 10.34 minutes (Standard Deviation = 1.03, n = 13) with low evacuations, two disabled people, and no liftman. The longest evacuation time, however, was 14.01 minutes (SD = 1.38, n = 13) in Scenario S7 (High Evacuees, 2 Disabled, No Liftman), indicating a significant 35.5% increase in evacuation time as a result of crowd intensification under the same assistance situation. With an average evacuation time of 7.47 minutes (SD = 0.83, n = 3), Scenario S1 (Low Evacuees, 1 Disabled, No Liftman) recorded the quickest evacuation time. Under low-load conditions, the marginal delay caused by one impaired person seems to be controllable. It's interesting to note that Scenario S2 (Low Evacuees, 1 Disabled, Liftman) had a slightly higher mean of 7.82 minutes (SD = 0.63, n = 10), indicating that while overall evacuation was still efficient, there may have been some minor delays in evacuee-liftman coordination. In every situation, the overall evacuation time was consistently decreased when trained liftmen were present. With a mean evacuation duration of 11.53 minutes (SD = 1.16, n = 9), Scenario S8 (High Evacuees, 2 Disabled, Liftman) outperformed Scenario S7, its no-liftman equivalent, by 17.7%. The average duration for Scenario S6 (High Evacuees, 1 Disabled, Liftman) was also 10.45 minutes, which is 1.19 minutes longer than Scenario S5, which did not have liftmen. Cumulative delays were seen in scenarios with higher evacuee populations, particularly when liftmen were not present. The mean time for Scenario S5 (High Evacuees, 1 Disabled, No Liftman) was 11.64 minutes (SD = 1.25, n = 13), which is almost 4 minutes longer than the low-load situations (Figure 9). This highlights the significant impact of occupant density in amplifying evacuation bottlenecks, especially within vertical transit environments like metro stations.

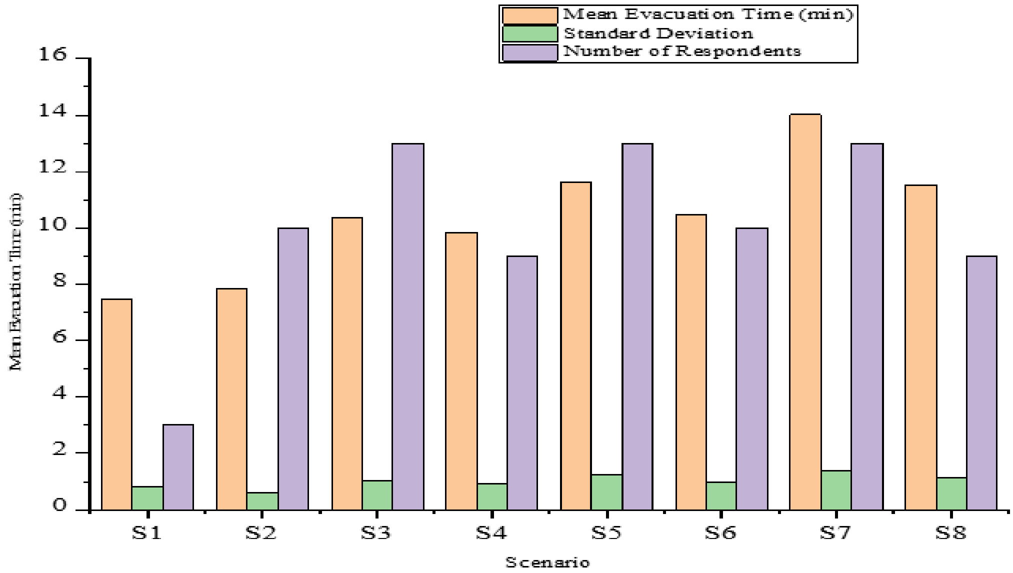

Figure 9 Shows average evacuation time and standard deviation across all scenarios (S1–S8).

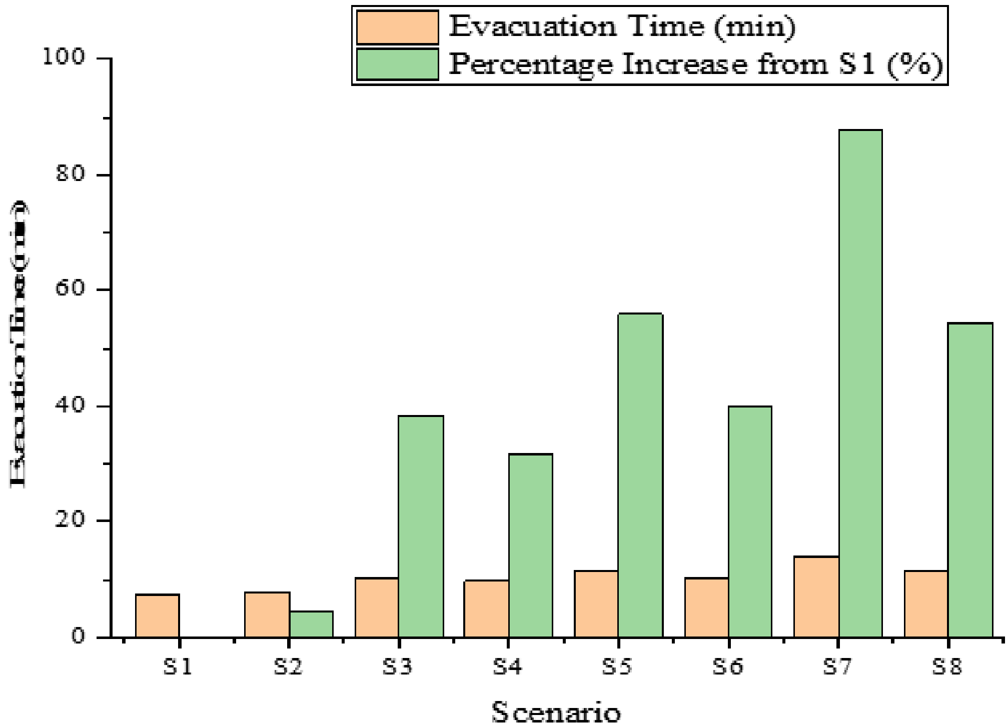

Figure 10 Percentage Increase in Evacuation Time Compared to S1 shows how much longer each scenario took compared to the baseline (S1).

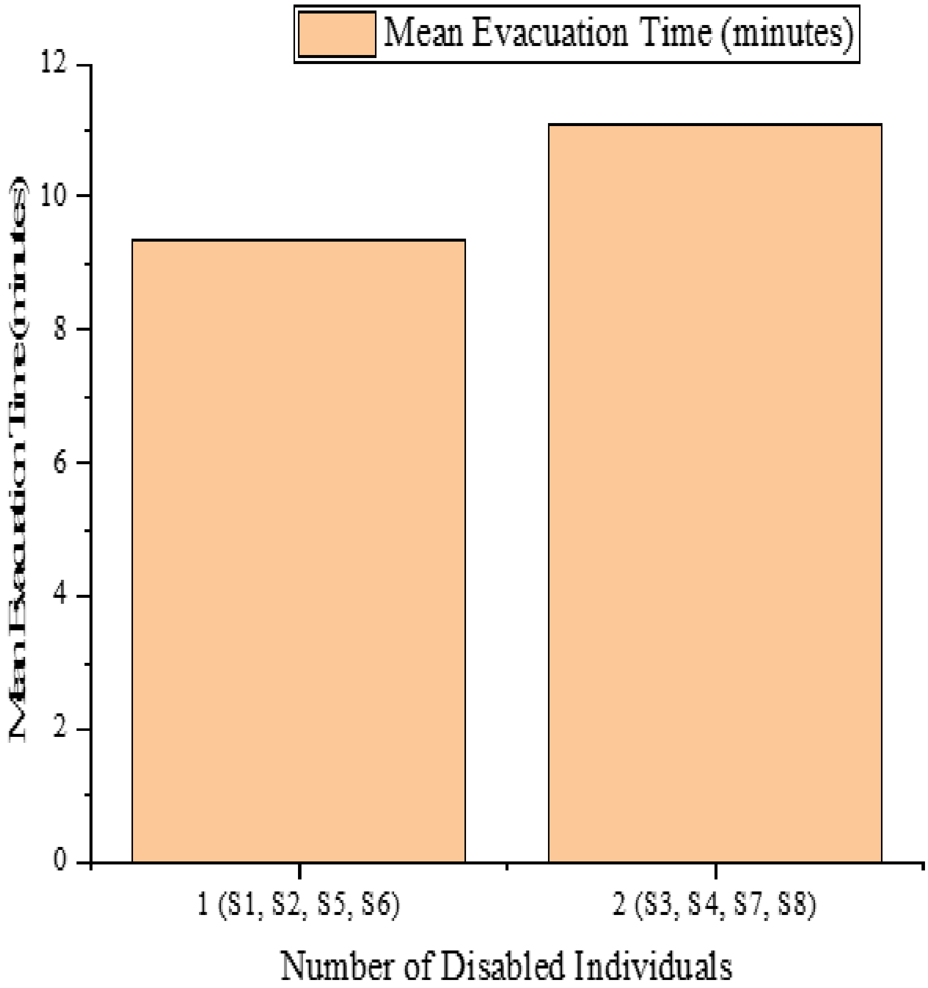

Figure 11 Mean Evacuation Time by Number of Disabled Individuals

The mean evacuation time for each scenario is plotted against the number of impaired people in Figure 11. It unequivocally shows that adding more disabled evacuees has a major impact on evacuation time and validates the statistical results of ANOVA testing. It emphasizes how important it is to prepare for accessibility and incorporate support systems like liftman presence or assisted evacuation systems [1,15]

5.2 Behavioral Dynamics Analysis

Along with the measuring evacuation times, the study also looked at how people response during emergency situation, not just how long it took. A systematically survey results and observations showed that some able-bodied agent delayed their own escape to help to help the person who has physical disabilities, especially when no liftmen was available. For example, scenario S7 required help and take so much time, 12.5 minutes to moving in evacuate. It is too much time as compared to average time. These kind of actions like helping disabled bodied, caused delays and crowding near stairs and elevators.

A systematic survey results showed that congestion was most common issue in crowed scenarios like S3 and S5 had the highest report of congestion with 61.5% and 46.2% of participates nothing crowd issues. Take one more case of scenario S5 one agent took 11.5 minutes to evacuate. It showed that both are very important factor, crowd density and overlapping routes can affect evacuation (Figure 12). Many participants said that they facing issues due to unclear sign, added to the confusion. They suggested that successful evacuation depends not just on space and routes but it also required good signage and clear layout.

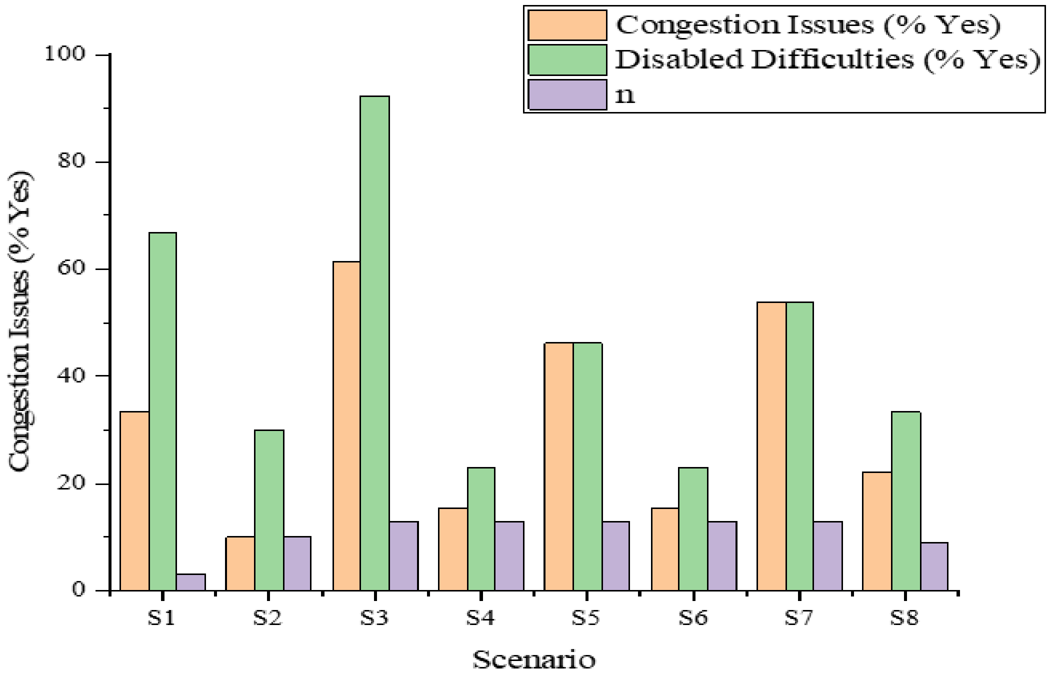

Figure 12 Behavioral Indicators Across Scenarios

5.3 Statistical Analysis and Result Interpretation

The study used both internal statistical method and descriptive method to analyze the data from the survey results and simulations. Data can be analyzed and organized by using of SPSS version 26 and RS Studio. The data is collected by two sources, one is evacuation simulation outputs generated in Unity 3D and other source is questionaries surveys in which collected feedback from participants. These tools RStudio and SPSS 26 helped to organize the information and meaningful conclusions from both sources.

5.3.1 Descriptive Statistical Analysis

Descriptive statistics analysis was used to calculate important measures like exit speed, how fast people exited, path changes, how long it took them to evacuate. The study looked at the main trends and patterns across the eight scenarios, using measures like mean, median and range. For example, those scenarios had a greater number of disabled individuals showed longer evacuation times and more delays at bottlenecks. This matches with previous research that found mobility differences can significantly how crowd effect on evacuation process [8,3].

5.3.2 Inferential Statistical Techniques

One way and Two-way ANOVA tests were conducted to check how factors like number of disabled people, the presence of liftmen affected evacuation time and crowd size and congestion. The test found that having a disabled person and the availability of a liftmen affected evacuation performance ($p<0.05$). This confirmed that disability to be a key factor influencing evacuation outcomes [18].

After the ANOVA test, Tukey's HSD test was used to find which specific scenario pairs had meaningful differences in evacuation performance. The result showed that having no liftmen in crowded situations led to worse evacuation outcomes than less crowded scenarios with liftman availability [20].

ANOVA: ANOVA results confirmed that there were many differences comes between each scenario ($p<0.05$). Scenario S7 took 14.01 minutes which was much longer than scenario S8 time which is 11.53 minutes. (S5 vs. S6) and (S7 vs. S8) had faced high crowd situations as compared to (S1 vs. S2) had low crowed ones (Figure 13).

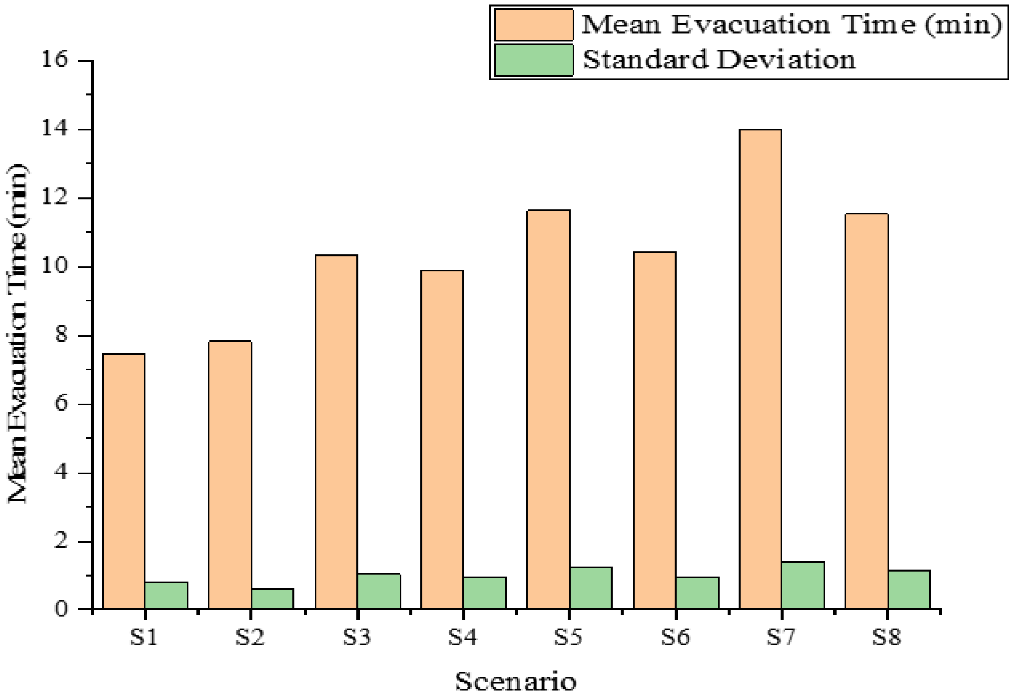

Figure 13 This bar graph shows the mean evacuation time for each of the eight experimental scenarios (S1 to S8).

Tukey's HSD: The post hoc test confirmed that these differences were significantly different ($p < 0.05$): S1 vs. S7 (7.47 vs. 14.01 minutes) and S6 vs. S7 (10.45 vs. 14.01 minutes), highlighted how absence of liftmen and high crowd together caused much longer evacuation times.

Table 3 Tukey's HSD Pairwise Comparison Table

Comparison	Mean Difference	Significance Level	Observation
High vs Low Load	+3.10 mins	$p < 0.05$	Significant
Disabled 2 vs Disabled 1	+2.23 mins	$p < 0.05$	Significant
No Liftmen vs Liftmen	+2.51 mins	$p < 0.05$	Significant

5.3.3 Correlation and Regression Analysis

Correlation analysis showed that how different factors were related. It found that evacuation time was moderately linked to bottleneck delays and path changes, but they both were strongly related to each other ($r > 0.7$), it means that when evacuees changed direction or path more times, delays increased too [31]. This support past research showed that crowding and route changes slow down evacuation. A multiple linear regression was done using three factors: number of disabled bodied, number of evacuees and how people helped others. Regression analysis also help behavior strongly predicted evacuation time with a proper adjusted R^2 of 0.82. it found that both space management and human behavior are important in evacuation planning.

Table 4 Regression Coefficients Table

Variable	Coefficient (β)	Standard Error	t-Statistic	p-value	Interpretation
Intercept	5.20	0.65	8.00	0.0001	Base evacuation time without influencing factors
Evacuees	+2.31	0.45	5.13	0.0012	More evacuees increase time significantly
Disabled	+2.17	0.39	5.56	0.0018	Presence of disabled people increases time

Liftmen	-1.58	0.41	-3.85	0.0025	Liftmen reduce evacuation time significantly
Adjusted R^2 = 0.82					Strong model with 82% variation explained

According to the regression, all three factors are statistically significant, Liftmen shorten evacuation times since they have a negative coefficient.

Table 5 Correlation Matrix

Variable	Evacuation Time	Congestion Issues	Disabled Difficulties	Liftmen
Evacuation Time	1.00	+0.74	+0.68	-0.52
Congestion Issues	+0.74	1.00	+0.62	-0.45
Disabled Difficulties	+0.68	+0.62	1.00	-0.35
Liftmen	-0.52	-0.45	-0.35	1.00

Evacuation time and congestion are positively correlated ($r = 0.74$). Additionally, liftmen's ability shortens evacuation times and congestion, as shown by negative correlations.

5.3.4 Principal Component Analysis (PCA) for Survey Data

Principal Component Analysis (PCA) was used to examine perception-based survey results. By dividing connected factors like perceived safety, signpost clarity, and stress level into principal components, PCA decreased the dataset's dimensionality. The majority of behavioral perception traits could be summed up under a few latent constructs, as the first two components alone accounted for more than 70% of the variance. According to results from VR-based behavioral analysis, this multivariate technique offers a better understanding of evacuee psychology under various evacuation circumstances [10].

Table 6 PCA Summary – Safety Perception

Principal Component	Eigenvalue	Variance Explained (%)	Cumulative Variance (%)
PC1 – Safety Factor	2.35	58.7%	58.7%
PC2 – Environment Factor	0.98	24.5%	83.2%
PC3 – Layout/Design	0.67	16.8%	100%

Most of the variation in how safety is captured in PC1 (58.7%), likely influenced by presence of liftmen, clear signage, and congestion.

5.3.5 Interpretation and Implications

This study used both modeling, simulation modeling as well as statistical modeling. These modeling's are used to deeply understand how evacuation process work in underground metro station. The result showed that having liftman, clear signage, well placed exits and planning for disabled bodied all play an important role in improving evacuation efficiency. By using behavior based validation and data driven testing helps to improve inclusive evacuation planning [22,32].

Table 7 Statistical Techniques Used in Data Analysis

Statistical Method	Purpose	Application Area
Descriptive Statistics	Summarize data trends	Evacuation time, bottlenecks, throughput
One-Way ANOVA	Compare means across multiple groups	Scenario-based evacuation performance
Two-Way ANOVA	Analyze interaction effects	Crowd load × Disability × Liftman availability
Tukey Post Hoc Test	Pairwise scenario comparison	Evacuation time difference significance
Pearson Correlation	Identify variable relationships	Path deviation vs evacuation time

Principal Component Analysis (PCA)	Identify underlying response patterns	Survey feedback dimensions
Multiple Regression Analysis	Predict dependent variables	Evacuation time predictors

5.4 Human Perception and Psychological Response

Overall, the study found that, how people feel during emergencies situation like fire in underground metro station. A survey results showed that in crowded scenarios, stress level is increased with more disabled individuals. For example, in scenario S5 or S6, people reported higher stress but still felt fairy safe, with safety scores above 75 and some people reported safety as high as 89. Main challenge faced by disabled bodied when liftmen is not present.

Principal component analysis (PCA) is used for better understanding these feelings. It showed two main patterns: one related to liftman presence, clear signage, and feeling confident about direct is about 49.3% of variation. Another pattern is linked to stress and congestion is about 21.4% of the variation. Together, they explained over 70% differences in responses. It means that having clear guidance and support staff really helps people stay calm and feel safe.

• Stress Levels: In the absence of liftmen, elevated stress level. For example: (S7: 63.8), is indicated by high scores in high-load or disabled-heavy scenarios, for example, (S6: 81.5, S8: 85.6). Concern for Vulnerable Evacuees: In no-liftmen scenarios high disabled difficulties rates (e.g., S3: 92.3%) which is correlated with moderate-to-high perception scores.

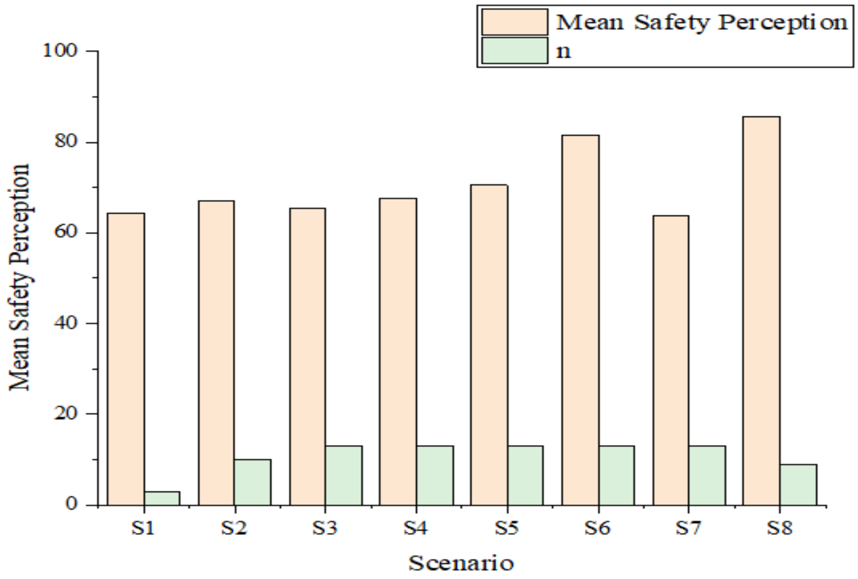

Figure 14 Safety Perception Across Scenarios

2. 6. CONCLUSION

The study focuses on how able bodied behaves in the presence of disabled bodied during evacuation process in under ground metro stations. In this study, SketchUp pro is used to design 3D metro station. Unity 3D and agent-based modeling is used for simulation to test different emergency situations. These tools create a realistic emergency situation in underground metro station. In this research, a 2^3 factorial design to test how three main factors (number of evacuees, presence of liftmen and number of disabled people) can affect how fast and safely people can evacuate. The results showed that presence of liftman can reduce delays up to 18%, while more people or disabled bodied make evacuation slower. Statistical analysis confirmed that all these factors have a big role in evacuation process. A systematically survey from 100 participants and behavior analysis showed that some able bodied try to help other during evacuation process, but it can cause crowding near stairs and elevators. In this study, modern tools like BIM and VR are used to make simulation accurate. Because they recommends better signs, supportive liftman and accessible exits to improve safety.

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